IMPROVED ELECTROSTATIC DESIGN OF THE JEFFERSON LAB 300 KV DC PHOTOGUN AND THE MINIMIZATION OF BEAM DEFLECTION

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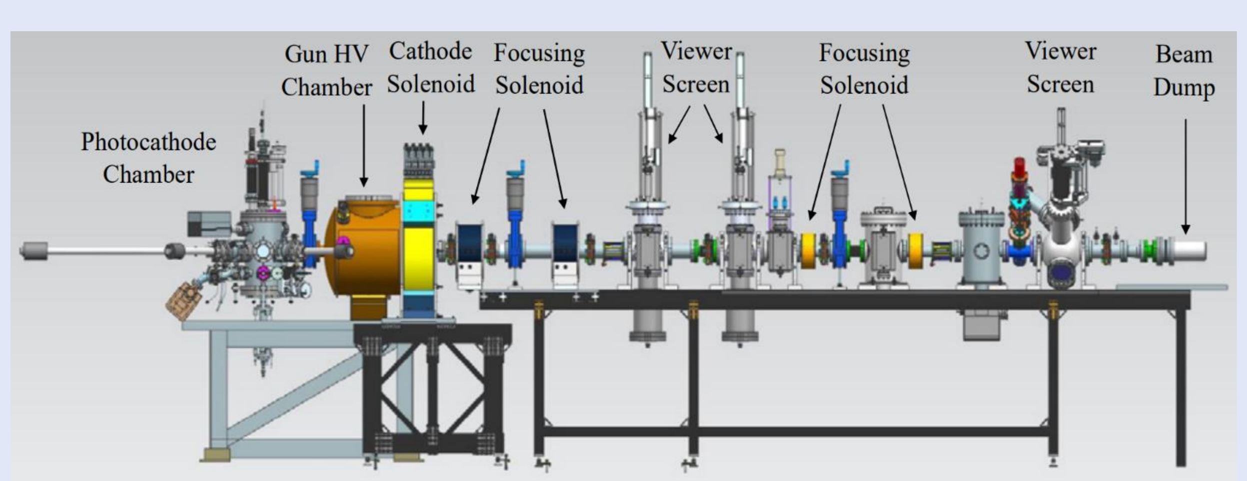
Introduction

Electron beam with high bunch charge and high repetition rate is required for electron cooling of ion beam to achieve the required high luminosity of proposed electron-ion colliders. Improved design of the -300 kV DC high voltage photogun at Jefferson Lab was incorporated toward overcoming the beam loss and space charge current limitation as experienced in the original design. To reach the bunch charge goal of ~ few nC within 75 ps bunches, the existing DC high voltage photogun electrodes and anode-cathode gap were modified to increase the longitudinal electric field (E_z) at the photocathode. The anode-cathode gap was reduced to increase the E_z at the photocathode and the anode aperture was spatially shifted with respect to the beamline longitudinal axis to minimize the beam deflection introduced by the geometric asymmetry of the inverted insulator photogun. The electrostatic design and the beam dynamics simulations were performed to determine the required modification. Beam based measurement from the modified gun confirmed the reduction of the beam deflection which is presented in this contribution.

Design Strategy and Experimental

- The accelerating electric field (E_z) at the photocathode sets the limit on the maximum charge density extractable from the photocathode
  - Increase E_z at the cathode by:
    - ✓ Removing the 25° Pierce geometry → flat cathode and flat anode front
    - ✓ Reducing the anode-cathode gap to 5 cm from 9 cm
- Inverted insulator and triple point junction shied, asymmetric NEG pumps altogether introduce asymmetric electric field in between the anode-cathode gap which results in deflecting the beam vertically at the exit of the anode, difficulty in beam steering, and ultimately beam losses
  - To correct the beam deflection with minimum changes:
    - ✓ Y deflection → Shift the anode aperture -1.6 mm vertically
    - ✓ X deflection → Replace existing NEGs with thinner strips
- To prevent high voltage insulator breakdown (i.e., arcing) and linearize the potential across the insulator
  - ✓ Design triple junction shield
- Reliable operation at -300 kV high voltage with high quality beam and 10^{-12} Torr scale vacuum without field emission and high voltage breakdown.
  - Minimizing field emission for longer photocathode lifetime
    - ✓ Optimize electrode shape (radius of curvature), size, and anode-cathode gap to have electric field ≤ -10 MV/m at -350 kV everywhere inside the chamber
    - ✓ Polished electrodes, High voltage conditioning
- Used CST Studio Suite's electromagnetic field solver for electrostatic design
- Used the particle tracking code GPT to simulate beam transport from the photocathode
- Beam deflection minimization is verified by comparing beam steering required for original and new photogun in a beam line of the Gun Test Stand:



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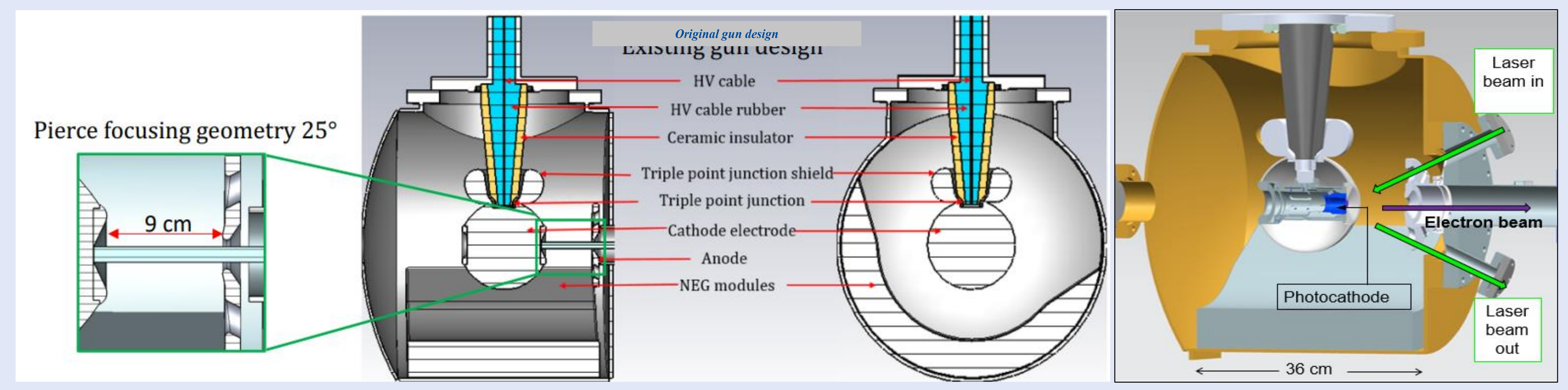
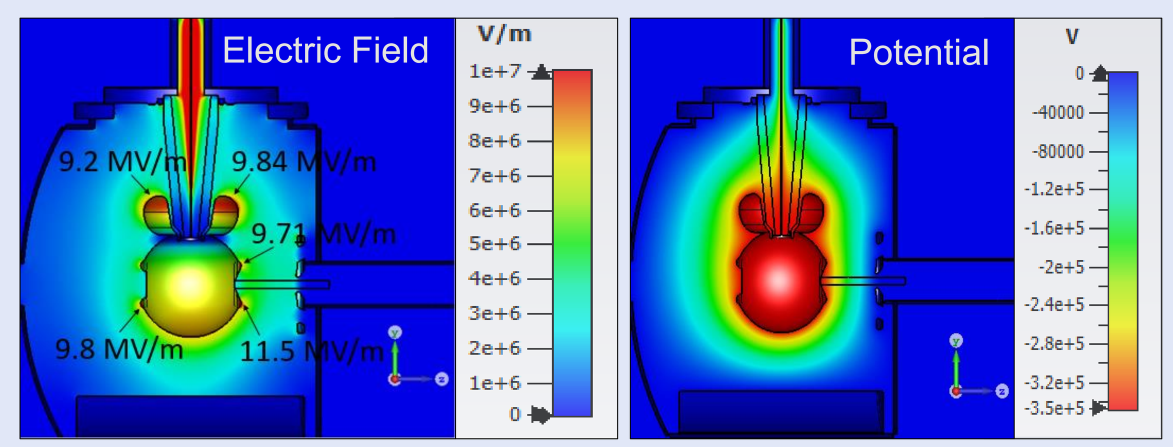
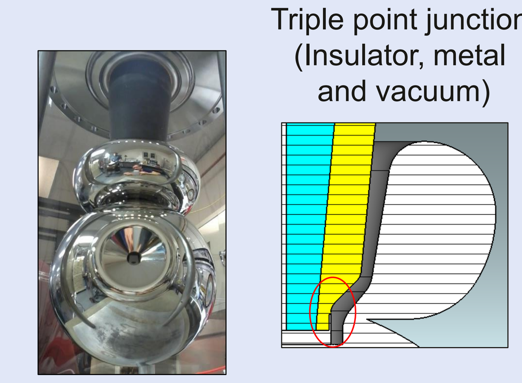
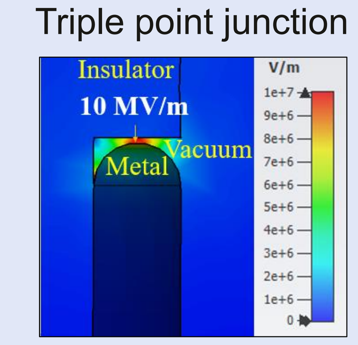
Original Photogun



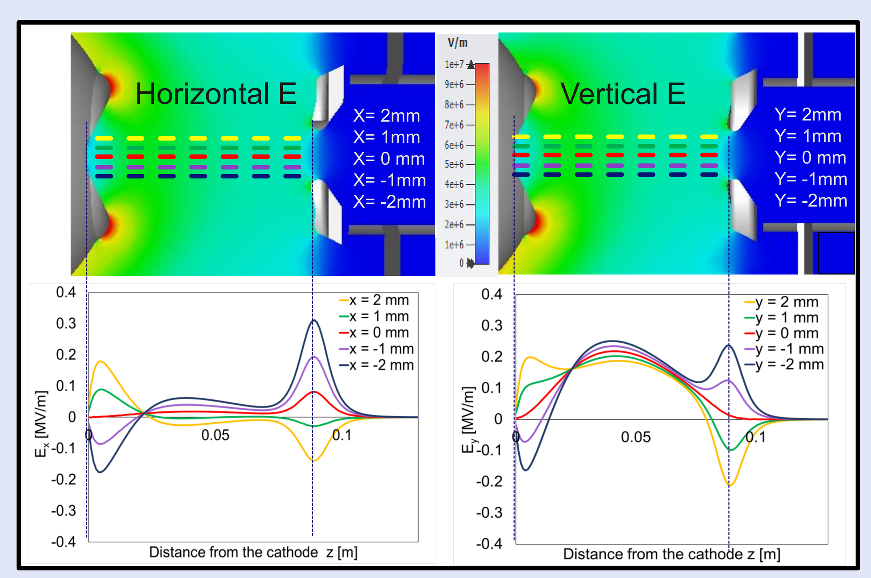


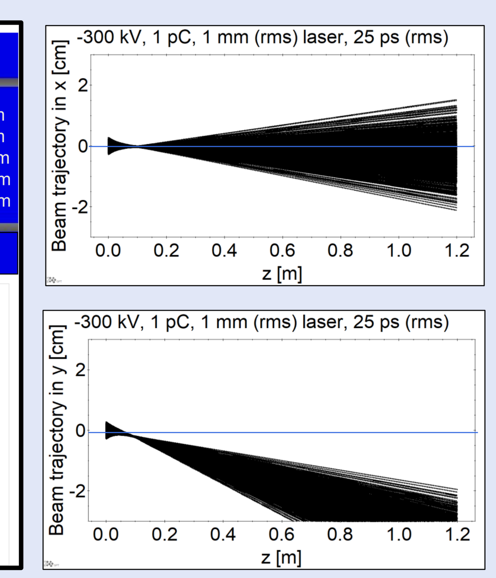


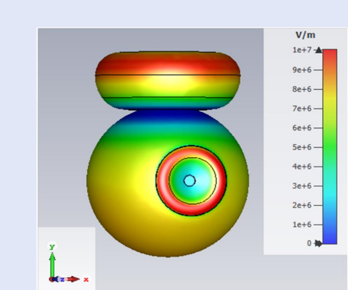
Triple point junction



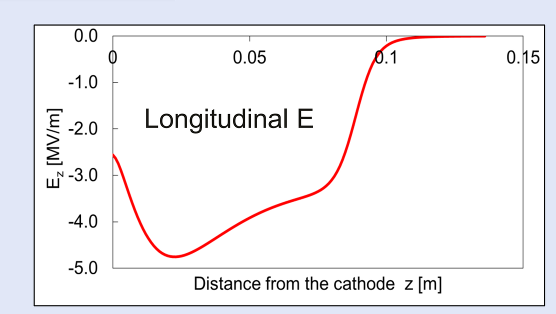
-350 kV at the cathode, 0 V at the anode



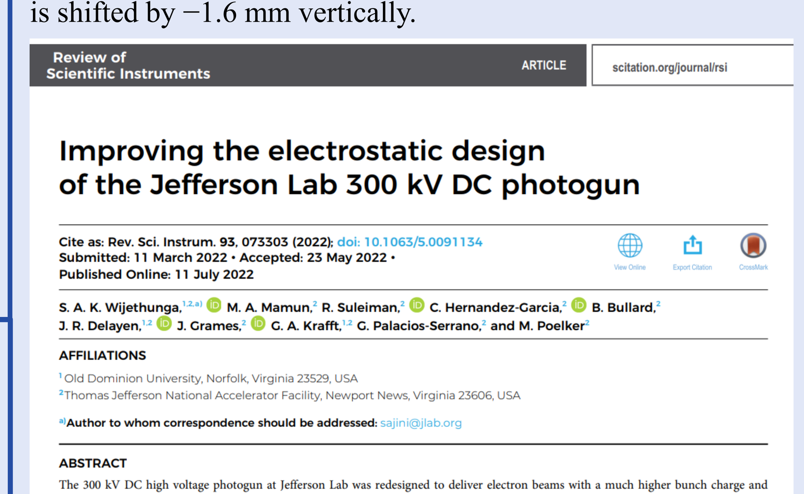




- The electric field at the cathode front is -2.5 MV/m
- E_z reached its maximum at ~ 2 cm and E_x and E_y fields focused at the same position due to the 25°Pierce geometry
- Asymmetry in E_x
  - Beam deflect 3 mm at z =1 m due to the asymmetry in placing the NEG pumps at the bottom of the gun chamber
- Huge asymmetry in E_y
  - Beam deflect 3.3 cm at z =1 m Due to the insulator and screening electrode



For the modified (flat) design: (a) front surface of the flat cathode that mates the spherical ball electrode and (b) the flat anode. The anode aperture (the hole at the center of the anode) is shifted by −1.6 mm vertically.


Review of Scientific Instruments — ARTICLE

Improving the electrostatic design of the Jefferson Lab 300 kV DC photogun

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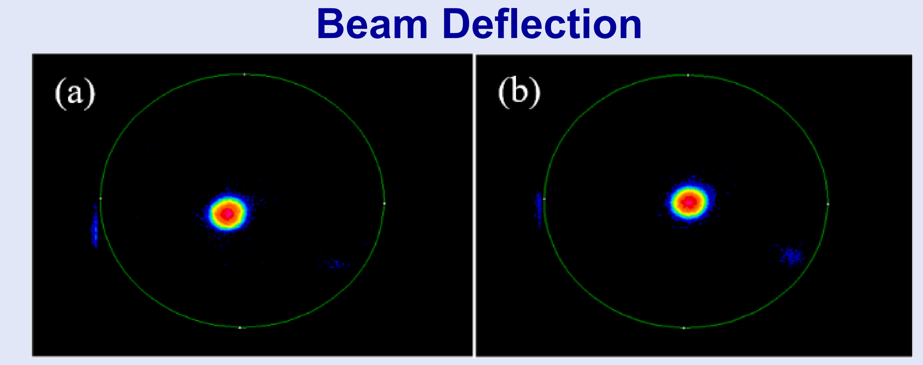
Beam Deflection

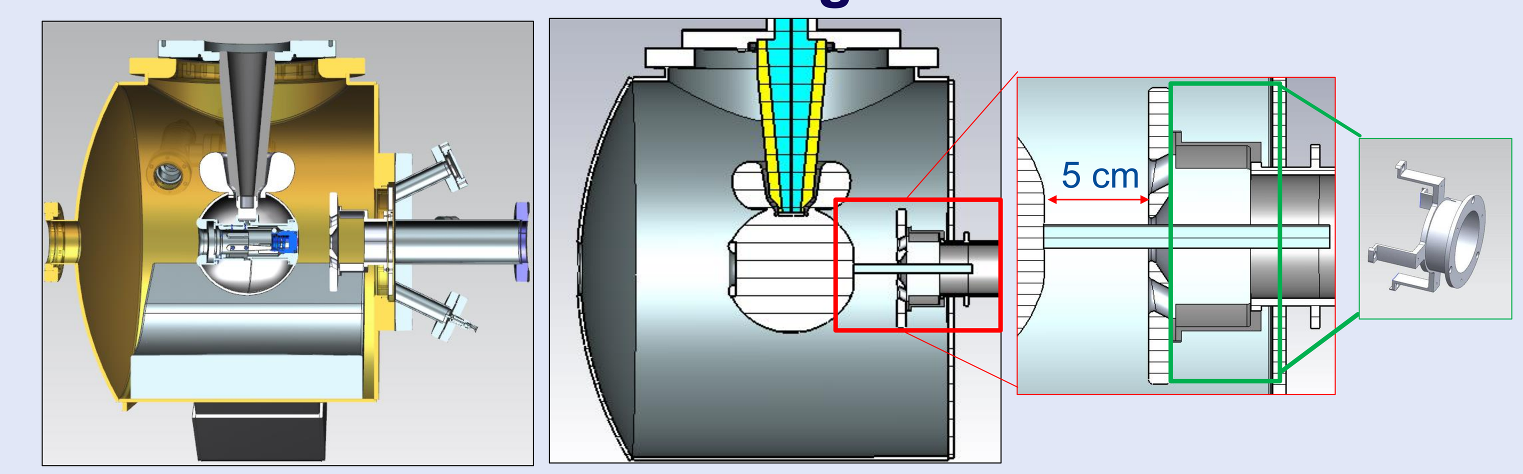


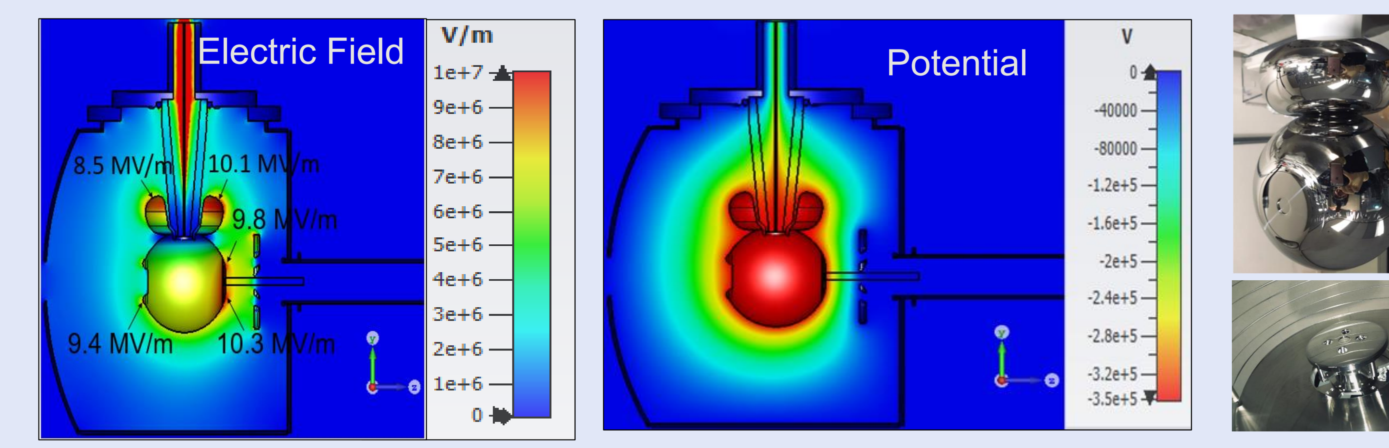
Electron beam for the redesigned photogun imaged on the first viewing screen 1 (a) with no beam steering, and, (b) beam centered on the first viewing screen with a very little steering by the first steering magnet set. For applied gun high voltage of -200 kV and laser spot of 0.35 mm rms size located at the center of the photocathode.

Table 1: Integrated Field (G cm) Applied on the First Horizontal and Vertical Steering Magnets to Center the Beam on the First Viewing Screen Located 1.5 m from the Gun. Listed for the Original and Redesigned Photogun for the Laser Spot Positioned at the Center of the Photocathode.

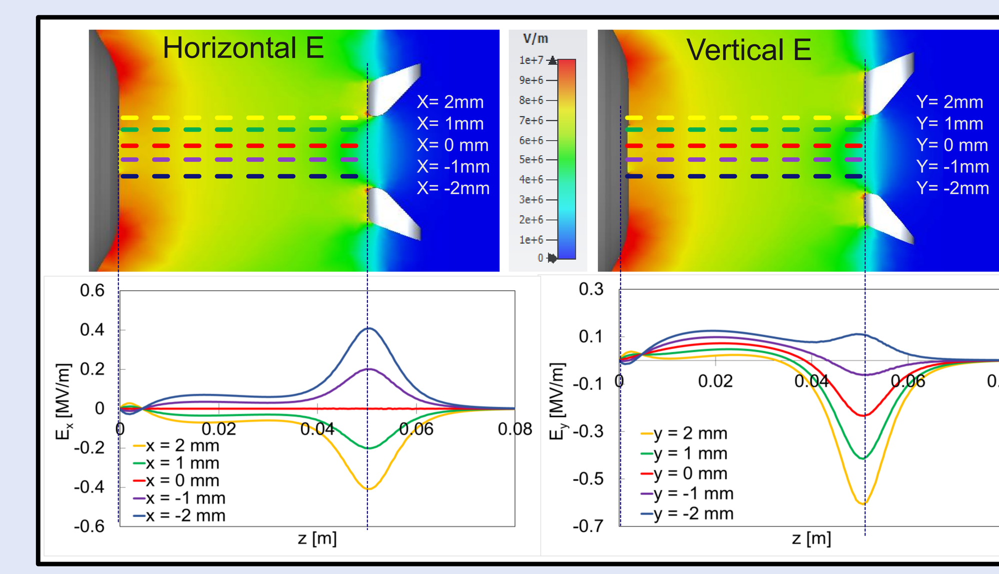
Steering Magnet	Original Gun	Modified Gun
Horizontal	21.3 G cm	-4.0 G cm
Vertical	83.0 G cm	3.0 G cm

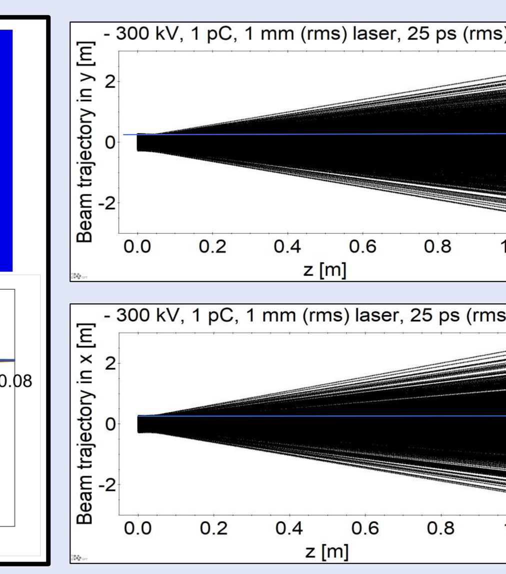
New Design

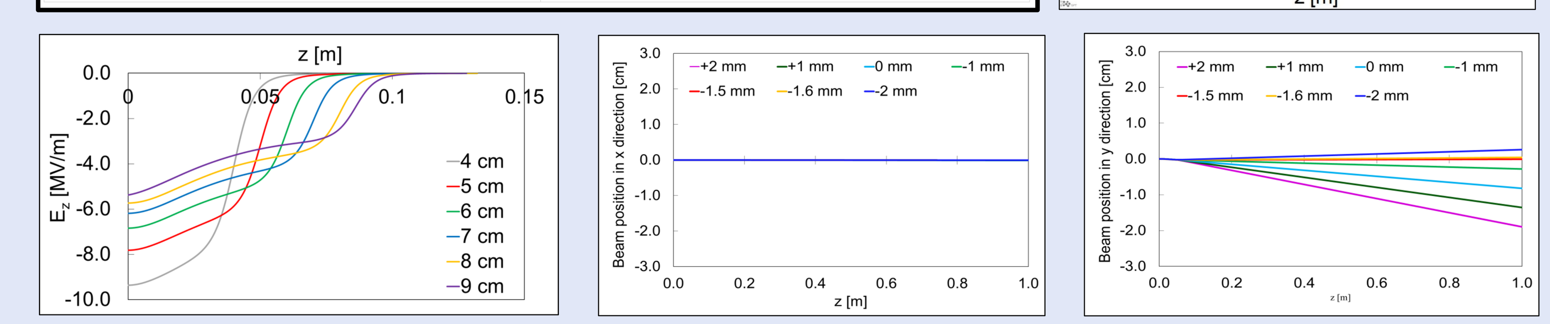




-350 kV at the cathode, 0 V at the anode



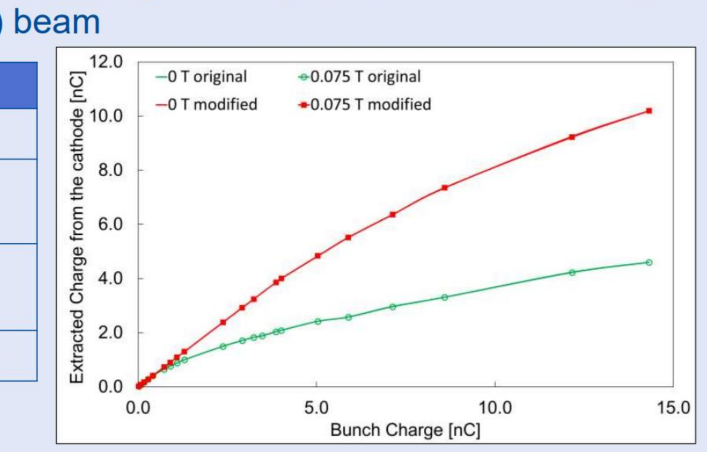




- **The electric field at the cathode front increased to -7.82 MV/m**

GPT simulations with the modified gun for the magnetized (0.075 T at the cathode) and non-magnetized (0 T at the cathode) beam

Parameter	Value
Gun high voltage [kV]	-300
Pulse width, Gaussian (FWHM) [ps]	75
Laser spot, Gaussian (rms) [mm]	1.64
Bunch charge [nC]	0.01 to 14



Summary

- Minimized the beam deflection by shifting the anode hole by -1.6 mm vertically which will be implemented in CEBAF polarized photogun. A tilted anode can also be used to accomplish the same goals of eliminating beam deflection, and that will be studied by the group in future.
- Increased E_z from - 2.5 MV/m to - 7.82 MV/m by removing the Pierce geometry and decreasing anode-cathode gap from 9 cm to 5 cm.
- Simulated charge extraction from cathode increased from 4.6 nC to 10.2 nC for the max deliverable bunch charge.
- Charge collected at the dump also increased with higher E_z.